# NASA GSFC
# Hydrological Sciences Branch

# USDA ARS
# Hydrology & Remote Sensing Laboratory

USDA-ARS HRSL
Hydrology & Remote Sensing Lab
Beltsville, Maryland, USA

## WORKSHOP
## January 30, 2003

**NASA HSB/USDA HRSL Meeting**
**Thursday, January 30, 2003**
**Bldg 005, Room 021**
**9:00am-4:00pm**

| | |
|---|---|
| 9:00am | USDA-Dr. Johnson, Director BARC Introduction |
| 9:05am | USDA-Dr. Weltz, National Program Leader |
| 9:15am | NASA HQ- Dr. Jared Entin, Program Manager, NASA's Water Cycle Activities |
| 9:25am | USDA-Dr. Walter Rawls, Research Leader, HRSL-Lab Mission |
| 9:30am | USDA Scientist Present (5 minutes) |
| | Dr. William Kustas -Remote Sensing-Based Land Surface Modeling |
| | Dr. Thomas Jackson -Satellite Microwave Remote Sensing of Soil Moisture: Current and Future Data for Hydrology |
| | Dr. Thomas Schmugge -Thermal Infrared Applications |
| | Dr. Wade Crow -Prospects for Improving the Accuracy of Land Surface Model Predictions via the Assimilation of Remote Sensing Products |
| | Dr. E. Raymond Hunt -Carbon Sequestration in Two Rangeland Ecosystems from Remotely Sensed APAR and $CO_2$ Eddy Flux Measurements |
| | Dr. Paul Doraiswamy -Evaluation of MODIS Products for Application In Regional Crop Conditions and Yield Assessment |
| 10:15am | Break |
| 10:30am | NASA GSFC-Dr. Paul Houser, Branch Head, HSB Branch Mission |
| 10:35am | NASA Scientist Present (5 minutes) |
| | Dr .Alfred Chang -Oceanic Rainfall Climatology |
| | Dr. Bhaskar Choudhury -Regional and Global Patterns of Carbon-Water-Energy Relations over Land Surface |
| | Dr. James Foster -Ongoing Passive Microwave Snow Research at GSFC |
| | Dr. Dorothy Hall -MODIS Snow and Sea Ice Products |
| | Dr. Michael Jasinski -Application of Satellite Remote Sensing to Mesoscale Hydrology |
| | Dr. Manfred Owe -Recent Advances in Microwave Remote Sensing of Land Surface Properties |
| | Dr. C. Adam Schlosser -Land-Climate Interactions and the Global Water Cycle |
| | Dr. Richard Kelly -Global Snow and Ice Monitoring Using Microwave Remote Sensing |
| 12:00noon | Break for lunch |

Regional
land surface heterogeneity
?
?

25ha

1) hydrologic zones
ET variability
Pest variability
2) One of the component in a Algorithm
3) where where to SAMPLE

1:00pm USDA Scientist Present (5 minutes)

Dr. Craig Daughtry -Crop Condition and Soil Management
Dr. Charles Walthall -Remote Sensing of Crops and Soils Information
Dr. James McMurtrey -Optical Based Measurements for Field Level Agronomic Management Decisions
Dr. Timothy Gish -Quantifying Subsurface Water and Chemical Fluxes
Dr. Jerry Ritchie -Spectral Measurements in Semiarid Rangelands
Dr. Walter Rawls -Hydraulic Soil Properties

1:40pm Short Break

1:45pm NASA Scientist Present (5 minutes)

Dr. Matthew Rodell -Terrestrial Water Storage from Remote Sensing and Modeling (Interested in OPE3 moisture data)
Dr. Christa Peters-Lidard -Local, Regional and Global Land-Atmosphere Modeling
Mr. David Toll -Land Surface Water & Energy Balance Estimation
Dr. Randal Koster -Seasonal Prediction and Soil Moisture
Ms. Alicia Joseph -Ground-Based Active/Passive Microwave Remote Sensing for Soil Moisture Retrieval
Dr. Xiwu Zhan -Improving Plant Photosynthesis and Stomatal Conductance Modeling for Enhanced Land Surface Models and Surface Soil Moisture Data Assimilation Using Kalman Filters
Dr. Rolf Reichle -Land Data Assimilation for Initialization of Seasonal Climate Forecasts
Dr. Ed Kim -Linking Surface Parameters and Microwave Signat
Dr. Paul Houser -Land Data Assimilation Systems

2:35pm Break

2:45pm Breakout Groups hosted by Paul and Walter:

1.) Land Modeling and Assimilation:
Data Assimilation with Remote Sensing
Land Surface Modeling with Remote Sensing

2.) Mapping Surface States with Remote Sensing:
Soil Moisture, Soil Temperature, Vegetation

3.) Remote Sensing Field Experiments:
OPE3, SMEX, CLPX, etc.

4.) Carbon Cycle - Vegetation Remote Sensing and Modeling:
Crop Assessment with Remote Sensing
Carbon Assessment with Remote Sensing

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Overview of the ARS Remote Sensing Program

The overview of the ARS remote sensing program will cover the following seven areas: (1) soil properties; (2) hydrology and meteorology; (3) crop management; (4) range management; (5) land use evaluation; (6) water quality assessment; (7) calibration and sensor development.

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NASA's Water Cycle Activities

A roadmap containing the direction of NASA's Office of Earth Science's Water Cycle program will be presented. The roadmap discusses various activities to be conducted between now and 2015, as well as the over all goal for the program. Activities, in the near term, that have possible over lap with USDA goals and activities will be highlighted.

# USDA ARS Hydrology & Remote Sensing Laboratory

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## Remote Sensing-Based Land Surface Modeling

Agriculture must be able to monitor and model land-atmosphere processes in order to respond, plan, and predict for relatively short term hydrologic extremes (floods and droughts) as well as more persistent climate events as a result of global warming. The key in developing such capabilities is understanding the hydrologic cycle and its connections to the energy and the carbon balance. Shifts in the spatial and temporal distributions of water will have dramatic impacts on energy and carbon budgets, which in turn affect weather on daily, seasonal, annual, and longer time scales. Understanding the interaction of the land surface and atmospheric circulation is a complex problem due to the high degree of variability in landscape properties. Observing technologies, both ground and remote sensing, must be developed and implemented in conjunction with appropriate land-atmosphere models in order to understand surface-air state coupling. Each approach offers unique capabilities that should be optimized in seeking a global product. This requires methodologies for scaling up our understanding of point level physics to watershed, regional and ultimately global scales.

To achieve this capability requires the development of process-based land surface algorithms and models using remote sensing technology and evaluate their utility for mapping surface states (i.e., soil moisture, surface temperature, vegetation cover, landscape roughness, soil erosion distribution, etc.) and water, energy and carbon fluxes from field and farm to watershed, regional and ultimately global scales. This necessitates research into issues of aggregation/ disaggregation or scaling of land surface states and understanding the feedbacks of landscape heterogeneity on atmospheric processes (surface-air state coupling). To effectively address these research topics ground-truth data covering a range of scales from point to field (for evaluating the processes), to watershed and regional scales (to explore scaling relationships) commensurate with remotely sensed observations that cover a similar range in spatial scales are being collected and processed. In addition, remote-sensing based land surface models evaluating exchange rates or fluxes of water, energy and carbon across the land-atmosphere interface are under development that vary in complexity depending on the objectives, spatial and temporal scales, and the availability of input data. An array of such physically-based remote sensing models will be implemented for testing remote sensing algorithms and aggregation/ disaggregation techniques. A Large Eddy Simulation (LES) model simulating atmospheric turbulent processes has been linked to remotely sensed boundary conditions for evaluating the feedbacks between surface states and the atmosphere under real landscape conditions.

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## Satellite Microwave Remote Sensing Of Soil Moisture: Current And Future Data For Hydrology

Soil moisture has been difficult to measure and map using conventional ground based point sampling. Wavelengths in the microwave portion of the spectrum respond to the amount of water present in the soil. This feature makes microwave remote sensing particularly attractive in hydrologic and water resources studies. Soil moisture retrieval using microwave remote sensing has been demonstrated using tower and aircraft instruments. The translation of this approach to satellites and the implementation in hydrologic applications has been limited by both the technology and the satellite systems that were available. Recent developments in both science and associated technologies now make the exploitation of the microwave region for soil moisture mapping feasible. There are a number of new satellite missions scheduled for the next five years. Passive systems provide frequent large-scale coverage at coarse spatial resolution. Active systems have high spatial resolution but poor temporal coverage. Tradeoffs and data fusion must be carefully considered.

Our research program will include; algorithm development for current and future soil moisture missions, implementation of validation networks, product validation, and application development. Much of this will involve large-scale field experiments in the U.S. and other countries. Daily soil moisture maps could contribute to a range of water resources applications such as establishing antecedent conditions for runoff prediction, irrigation management, and climate analysis.

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Research

- Surface temperature and emissivity determination from satellite thermal infrared data produced by the ASTER instrument on the Terra satellite
- Mapping of surface emissivities over large areas for radiation balance studies
- Use remotely sensed data in models to estimate the components of the surface energy balance.

## Thermal Infrared Applications

The observed surface temperature is an indicator of the surface energy balance and thus is a useful diagnostic variable. The problem arises as to how well we can measure it from space for land surfaces. The 90m resolution of ASTER thermal infrared data affords the possibility of comparing space observations with ground measures of surface temperature. This is one of the objectives of our field campaigns at the Jornada Experimental range in New Mexico. An important aspect of this problem is to separate the temperature and emissivity effects in the thermal infrared observations. For ASTER data this is performed with the Temperature Emissivity Separation (TES) algorithm developed for use with the satellite data. The efficacy of TES is also being evaluated at the Jornada and the nearby White Sands National Monument.

The ASTER/TES results provide a new tool for evaluating the spatial and temporal variations of the surface emissivity on a global/regional basis. This is particularly important for those regions of the earth with large percentages of exposed soil or rocks, e.g. deserts. An example of this has been performed for a large portion of the Sahara desert in North Africa where the observed emissivities are quite different from the values currently used. These data will be useful for improving the emissivity maps used for determining the radiation balance in atmospheric models.

The resulting surface temperatures from the ASTER/TES process are being used in models for estimating the components of the surface energy balance. Two models for incorporating the remotely sensed data are currently being evaluated: the Two Source Energy Balance (TSEB) model and the Surface Energy Balance Algorithm for Land (SEBAL) model.

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Prospects for Improving the Accuracy of Land Surface Model Predictions via the Assimilation of Remote Sensing Products

An ongoing challenge for hydrologists and remote sensing scientists is the design of experiments to demonstrate the value - in any - of remote sensing observations for efforts to monitor and/or predict surface water and energy balance processes. The need is especially pressing for remote observations of surface geophysical state variables like soil moisture and skin temperature. One efficient utilization of remote surface state observations is within the context of a data assimilation system designed to merge surface state predictions from numerical models with remote observations of the land surface. Such systems contain at least three components: a numerical land surface model, an emission model to convert land surface model predictions into observable quantities (e.g. brightness temperature), and an assimilation algorithm. The "value" of remote sensing observations therefore depends on a myriad of factors including the quality of non-updated open-loop model predictions, the optimality of the data assimilation approach, and the accuracy of the observation model. One basic benchmark for data assimilation approaches should be the accuracy of model predictions (e.g. evapotranspiration) obtainable from non-updated open-loop model simulations.

Two key weaknesses of open-loop land surface models are their reliance on uncertain measurements of model forcings (i.e. rainfall, radiation, and meteorological variables) and parameter selection ambiguities presented by their complex representation of surface processes. Both shortcomings represent potential openings for data assimilation strategies focused on remote sensing retrievals of surface state variables. Under this umbrella framework, current research topics include the use of Ensemble Kalman filtering to assimilate surface L-band microwave brightness temperatures observations and compensate surface model predictions for errors arising from poor measurement of rainfall and examining the use of variational data assimilation strategies for reducing the parameter requirements for surface energy balance models driven by remote radiometric temperature observations.

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Carbon Sequestration in Two Rangeland Ecosystems from Remotely Sensed APAR and $CO_2$ Eddy Flux Measurements

Net ecosystem exchange (NEE) is the difference between photosynthesis (also called gross primary production, GPP) and autotrophic and heterotrophic respiration (from plants and decomposers, respectively). GPP is estimated from remotely-sensed Absorbed Photosynthetically Active Radiation (APAR) by knowing the efficiency of radiation use ($\epsilon$). It can be shown that in a regression of NEE and APAR, the slope is equal to $\epsilon$ and the intercept is equal to mean total respiration. NEE is being measured throughout the world with the eddy covariance technique to estimate carbon sequestration.

Aircraft measurements were acquired in 1999 over two southeastern Wyoming landscapes, a mixed-grass prairie and a sagebrush steppe. A linear relationship between NEE and APAR was used to determine $\epsilon = 0.51$ g C $MJ^{-1}$ APAR. Chamber measurements of ecosystem respiration in 1998 and 1999 were used to develop a functional relationship with daily average temperature; the $Q_{10}$ of the relationship was 2.2. Advanced Very High Resolution Radiometer Normalized Difference Vegetation Index (AVHRR NDVI) and climatological data were used to determine APAR. For 1995 to 1999, GPP was determined from the weekly product of APAR and $\epsilon$, and respiration was calculated from average daily temperature. The sagebrush site was a net carbon sink, whereas the grassland site was in carbon balance.

Net ecosystem flux measurements are important data to parameterize radiation-use-efficiency models. The long time series and regional coverage of AVHRR NDVI and large to determine areas of carbon sequestration avoids problems associated with short-term, small-scale sampling with flux measurements.

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Evaluation of MODIS Products for Applications In Regional Crop Conditions and Yield Assessment

Regional monitoring of agricultural crop condition has traditionally been accomplished using NOAA AVHRR (1 km) data. New methods for assessing crop yields are by integrating biophysical parameters retrieved from remotely sensed imagery with crop simulation models. The 1-km AVHRR imagery is unsuitable for retrieval of field level parameter and the Landsat data is not frequent enough for monitoring changes during the critical period of crop growth. The MODIS imagery offers an opportunity for a better resolution and a daily coverage required for operational applications. The objective of this research is to assess the application of MODIS data for operation crop condition and yields. Additionally, to compare MODIS products, LAI and fPAR with independently derived LAI/fPAR parameters from MODIS reflectance data. Both sets of parameters are input to crop simulation models for mapping regional crop yields. A Field study was conducted in McLean county Illinois, USA. Twenty corn and soybean fields were monitored for crop reflectance, LAI and other growth parameters. A radiative transfer model was used to develop the LAI and fPAR parameters from the MODIS 250-m data. The magnitude and spatial variability of crop yield estimates show significant difference, primarily due to errors in the classification of crop type. Recommendations to improve MODIS derived operational parameter are presented.

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Monthly Oceanic Rainfall Derived from SSM/I and TMI
Rain Climatology
Error Analysis
ITCZ & Diurnal Cycle

Snow Depth & Water Equivalent Derived from AMSR
Algorithm Development
Product Validation

# REGIONAL AND GLOBAL PATTERNS OF CARBON-WATER-ENERGY RELATIONS OVER LAND SURFACE


ABSTRACT

Effort is being made to calculate regional and global patterns, and inter-annual variation, of evaporation (individual fluxes of transpiration, soil evaporation, and evaporation of intercepted water), net radiation, gross and net carbon accumulation, and assess such indices as evaporative fraction (ratio of total evaporation and net radiation), transpiration efficiency (ratio of net carbon accumulation and transpiration), water use efficiency (ratio of net carbon accumulation and total evaporation), radiation use efficiency (ratio of net carbon accumulation and intercepted photosynthetically active radiation), and carbon use efficiency (ratio of net and gross carbon accumulation). These calculations are being done using biophysical process-based models, with parameters determined from field observations (e.g., foliage nitrogen content per unit leaf area index, maximum rate carbon accumulation by leaves), satellite data (e.g., solar radiation, air temperature, vapor pressure deficit) and four-dimensional data analysis (friction velocity).


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Ongoing Passive Microwave Snow Research at GSFC

Passive microwave algorithms have now been developed for North America, Eurasia and South America - those continents where seasonal snow cover has an impact on climate and water resources. Considerations for variations of snow crystal size and fractional forest cover are now included in the algorithms, and work is progressing on including information about how snow crystals evolve during the course of the snow season. For our research, not only has satellite and airborne remote sensing been employed, but electron microscopy has been utilized as well. We have a long history of working with the USDA in an effort to determine which snow crystal characteristics are most important in terms of their effects on passive microwave algorithms. In addition to the above work, research is now underway on quantifying the errors associated with passive microwave snow estimates.

MODIS Snow and Sea Ice Products

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On December 18, 1999, the Terra satellite was launched with a complement of five instruments including the Moderate Resolution Imaging Spectroradiometer (MODIS). Many geophysical products are derived from MODIS data including global snow-cover and sea ice products. MODIS snow and ice products are available through the National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC). MODIS snow-cover products represent potential improvement to or enhancement of the currently available operational products mainly because the MODIS products are global and 500-m resolution, and have the capability to separate most snow and clouds. Also the snow-mapping algorithms are automated which means that a consistent data set may be generated for long-term climate studies that require snow-cover information. The MODIS snow product suite begins with a 500-m resolution, 2330-km swath snow-cover map which is then gridded to a sinusoidal grid to produce daily and 8-day composite tile products. The sequence proceeds to a climate-modeling grid (CMG) product at ~5.6-km spatial resolution, with both daily and 8-day composite products. Each pixel of the CMG contains fraction of snow cover from 40 – 100%. Measured errors of commission in the CMG are low, for example, on the continent of Australia in the spring, they vary from 0.02 – 0.10%. Near-term enhancements include daily snow albedo and fractional snow cover. Validation of the products is ongoing.

Abstract modified from: Hall, D.K., G.A. Riggs, V.V. Salomonson, N.E. DiGirolamo and K.J. Bayr, 2002: MODIS Snow-Cover Products, *Remote Sensing of Environment*, 83:181-194.

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RESEARCH AREAS:

1. Investigation of the influence of land surface heterogeneity on mesoscale surface fluxes using the coupled MM5/PLACE model.
2. Estimation of vegetation aerodynamic roughness for momentum using satellite imagery.
3. Large-Basin precipitation runoff modeling: Ob River in Northern Eurasia.
4. Altimetric remote sensing of Amazon discharge.
5. Application of satellite imagery to regional malaria prediction.

# Recent Advances in Microwave Remote Sensing of Land Surface Properties

Manfred Owe

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A new technique to retrieve land surface properties with satellite microwave observations has been developed. Values for surface soil moisture, vegetation optical depth, and surface soil temperature are derived. The methodology uses a radiative transfer model together with a non-linear optimization procedure to solve simultaneously for surface soil moisture and vegetation optical depth. Surface temperature is derived offline from 37 GHz vertical brightness temperatures. At the moment, the procedure assumes known constant values for the scattering albedo and surface roughness. The approach is somewhat unique, in that it requires no field observations of soil moisture or canopy biophysical properties for calibration purposes, and may be used at any wavelength. Traditional retrieval techniques have frequently relied on ground observations of soil moisture, which were either related directly to the soil emissivity, or used in a radiative transfer equation to then solve for some of these unknown parameters as residuals. These calibration-based methods are seldom ideal, since they are often not directly transferable to other geographic locations or applicable when vegetation conditions change. Additionally, they frequently require measurements of surrogate parameters (e.g. NDVI) to quantify these unknowns. The procedure is tested with historical brightness temperature observations from the Scanning Multichannel Microwave Radiometer. Soil moisture, canopy optical depth, and surface temperature retrievals have compared well with time series of soil moisture field observations, satellite-derived vegetation index, and snowcover data.

# Dr. Richard Kelly


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### General Research Interests

I am a visiting scientist at NASA/GSFC and member of the Research Faculty at Goddard Earth Science and Technology Center, UMBC. As a physical geographer, my broad research interests are concerned with monitoring and modeling hydrological processes, especially in cryospheric environments, using earth observation data. I am particularly interested in:

- developing and applying novel methodologies that use data/imagery from satellite microwave instruments for global snow and ice hydrology;
- understanding errors associated with satellite-based snow depth/water equivalent retrievals;
- exploring ways that ground measurements of hydrological parameters can be scaled-up to test satellite-based estimates of earth surface hydrological processes;
- investigating the relationship between snow cover variations and climate variations in the global satellite microwave imagery record;
- assessing the utility of earth observation for glacier and ice cap mass balance measurements.

Other recent work has included the investigation of radar remote sensing for soil moisture mapping and how spatial variations in ground measured soil moisture relate to spatial variations in radar backscatter responses. I am currently involved in a concept design study to develop a spaceborne microwave (active/passive) instrument for global snow depth or water equivalent estimation.

**Selected recent/forthcoming papers:**


Kelly, R.E.J., Davie, T.J.A. and Atkinson, P.M. (in press) Explaining temporal and spatial variation in soil moisture in a bare field using SAR imagery, *International Journal of Remote Sensing*.

Kelly, R.E.J. (2002) Determination of the ELA on Hardangerjøkulen, Norway during the 1995-1996 winter season using repeat pass SAR coherence, *Annals of Glaciology,* 34: 349-354.

Hall, D.K., Kelly, R.E.J., Riggs, G.A., Chang, A.T.C. and Foster, J.L. (2002) Assessment of the relative accuracy of hemispheric-scale snow-cover maps. *Annals of Glaciology,* 34: 24-30.

Kelly, R.E.J. and Chang, A.T.C. (in press) Development of a passive microwave global snow depth retrieval algorithm for SSM/I and AMSR-E data, *Radio Science*.

Kelly, R.E.J., Chang, A.T.C, Tsang, L. and Foster, J.L. (in press) Development of a prototype AMSR-E global snow area and snow volume algorithm, *IEEE Transactions on Geoscience and Remote Sensing*.

Kelly, R.E.J., Drake, N. and Barr, S.L. (editors) Spatial Modelling of the Terrestrial Environment, Chichester: UK: John Wiley and Sons. Ltd. (forthcoming 2003).

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Crop Condition and Soil Management

Crop residues are the portions of a crop that are left in the field after harvest. These crop residues reduce soil erosion, add nutrients to the soil, and improve soil structure. Crop residues also affect water infiltration, evaporation, and soil temperatures. Thus the presence of crop residues on the soil surface influences the flow of nutrients, carbon, water, and energy in agricultural ecosystems. Current methods of measuring crop residue cover are inadequate for evaluating the effectiveness of conservation tillage practices over fields and regions. One promising remote sensing approach for discriminating crop residues from soil is based on a broad absorption band near 2100 nm that appears in plant materials but is absent in most soils. The cellulose absorption index (CAI) measures the relative depth of this absorption feature and is linearly related to crop residue cover. Soil tillage, a crucial input to most soil carbon models, can be estimated based on crop type and residue cover soil. Research is underway to evaluate both AVIRIS and Hyperion images for assessing crop residue cover and soil tillage.

Leaf chlorophyll content is an good indicator of plant N status. However, in remotely sensed images, changes in leaf chlorophyll are often confounded with variations in soil color and plant growth. Two categories of spectral vegetation indices have been identified. One group of spectral vegetation indices minimized contributions of background reflectance and responded primarily to leaf area index, while the other group of indices responded to both leaf chlorophyll concentrations and background reflectance. Selected pairs of these spectral indices plotted together produced isolines of leaf chlorophyll concentrations that were largely independent of soil background and leaf area index. Research is underway to identify robust spectral indicators of leaf chlorophyll content that can be used for site-specific applications of N fertilizers to optimize crop growth and yield.

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Remote Sensing of Crops and Soils Information

Information about vegetation status and soil conditions is needed for many agricultural and natural resources management decisions. Foliage density expressed as leaf area index (LAI) is a quantification of plant productivity that can be retrieved via remote sensing. Crop LAI is used for a variety of purposes focused on the crop itself, and can be used for schemes to assess soil characteristics. Detailed within-field assessments of LAI appear to be especially beneficial for precision farming applications. Unfortunately, retrieval of LAI at high spatial resolution often fails using spectral vegetation index-based methods that rely solely on spectral information. Procedures exploiting both the spectral and spatial information content of remotely sensed imagery are being examined as a means of improving LAI retrieval at high spatial resolution. Additionally, a hybrid algorithm employing both spectral vegetation indexes and radiative transfer model inversion is also being assessed as an alternative for accurately mapping LAI from imagery. Imagery from both airborne and spacecraft platforms are being tested.

Characterizing soil conditions via assessments of the status of the overlying vegetation canopy is an alternative to laborious manual sampling. Crop LAI can be modeled as a function of soil water holding capacity (SWHC) and weather data using various models. Model inversion of SWHC driven by crop LAI mapped from remotely sensed imagery coupled with weather data appears possible. Crop LAI maps during drought conditions coupled with soil data and digital elevation maps also appear to provide surrogate indications of subsurface preferential water and chemical flow pathways. Current investigations on SWHC retrieval are focused on driving neural networks, regression trees, and an ET-based model with LAI and weather data. The surrogate indicator analysis is addressing relationships between LAI and locations of subsurface flow pathways identified using a GPR-DEM-GIS procedures.

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Optically Based Measurements for Field Level Agronomic Management Decisions

Nutrient availability for viable plant production is the second only to water availability in assuring sustained crop production. Of the sixteen essential nutrients necessary nitrogen (N) is the most important in driving the plant production/biomass cycle. Deficient supply or inadequate N uptake can adversely affect crop production goals and over fertilization with N has been found to be responsible for contamination to our water resources. Optically derived remote sensing techniques for detecting N needs in corn crops are being assessed. Passive reflectance sensing and active fluorescence sensing are under investigation to determine there utility in making efficient agronomic management decisions about site specific N needs in crop production. Reflectance and fluorescence index methods have shown promise for sensing changes in the primary plant pigments (chlorophylls and caroteniods) and productivity of crop canopies and are highly affected by N availability.

One third of the arable U.S. crop acreage has been classified as having highly erodible land types by the USDA, Natural Resource Conservation Service. Increased biomass and the resulting crop residues has been shown to slow soil loss and have the beneficial effects of increasing organic matter in our soil resources for improving crop growth and enhancing carbon sequestration in the environment. Management practices of no-till farming and the growing of increased biomass crop varieties have been suggested to increase crop residue production and retention on U.S. crop lands. Reflectance and fluorescence optical methods are being examined for their ability to remotely sense increases in residue coverage, biomass and over-all carbon accumulation on crop lands.

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Quantifying Subsurface Water and Chemical Fluxes

Non-point source pollution is the major contamination pathway leading to the deterioration of surface and subsurface water quality. Eliminating or reducing the detrimental impacts of agriculture on water quality is important since chemicals that leave agricultural lands through runoff or subsurface leaching pose not only a threat to human health and the environment, but also represent an economic loss to the farmer. Furthermore, a poor understanding of soil water dynamics is the factor limiting our ability to quantify within field yield variability. Unfortunately, fundamental watershed-scale processes governing the dynamic behavior of chemical transport through soil to neighboring ecosystems are so poorly understood that strategies for mitigating chemical contamination cannot be accurately formulated. Traditionally, soils have been conceptualized as a series of homogeneous columns, each with a specific set of hydrologic properties. Identifying and determining the number of "representative" soil columns with their respective hydrologic parameters, along with their spatial distribution has not been successful at the field or watershed scales. Recent studies have shown that a process referred to as preferential fluid dynamics is often the dominant transport process on a field-scale. When preferential flow is dominant a small fraction of the available pore space (generally <1%) is utilized in transporting over 60% of the applied chemicals to groundwater and so is a critical process but extremely difficult to quantify. While random sampling with soil cores or suction lysimeters is an effective means for measuring chemical transport in soil where matrix flow conditions dominate those same methods fail to capture preferential flow. A radical paradigm shift in how we conceptualize and monitor water and chemical transport is necessary if we are to accurately quantify water and chemical fluxes on a watershed scale.

Recently, a method based primarily on ground-penetrating radar mapping of soil structures accurately identify subsurface convergent water flow pathways. These flow pathways become especially active when preferential flow was active. Continuous monitoring of these flow pathways should allow watershed quantification of subsurface water and chemical fluxes at the small watershed scale. Furthermore, preliminary results indicate that the location of these flow pathways serve as environmentally sensitive regions and dramatically influence within field yield variability. Developing surrogate indicators of these flow pathways using remote sensing and soil data bases in a GIS framework will be critical to extending these results to the agricultural community

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Spectral Measurements in Semiarid Rangelands

Spectral measurements of vegetation communities of the semiarid grasslands in the Jornada Experimental Range LTER in New Mexico, USA were measured at ground level using an Analytical Spectral Devices (ASD) Spectrometer on a 30x30 m grid at 5 m intervals, from an airplane with the MODIS/ASTER Simulator (MASTER) with a 3x3 m resolution, and from space with the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with 15x15 m resolution in May 2001 and with the ASD and ASTER in September 2001. Four communities (Grass, Transition, Mesquite, Creosote) were sampled at the Jornada. Reflectance increased from Grass to Transition to Shrub communities from all three platforms. Patterns of reflectance were similar from the three platforms with MASTER and ASTER having similar absolute values. Comparison of absolute values of ASD ground measurements with MASTER and ASTER measurements differed with different vegetation communities but in general ASD measurement were slightly lower than MASTER or ASTER measurements. These differences are assumed to be related to the different sized footprints of the instruments. In general, as ground cover decreased from Grass to Transition to Shrub communities, reflectance increased indicating a potential for change in heat and water balance of these ecosystems if shrubs continue to expand into the Grass communities.

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## Hydraulic Soil Properties

Knowledge of hydraulic properties is a key element in hydrologic modeling. Laboratory and field methods for determining soil hydraulic properties are time consuming and expensive. Average soil hydraulic properties developed in the early 1980's according to soil texture or pedotransfer functions which relate basic quantitative soil properties such as soil particle size, organic matter, bulk density, etc.to soil hydraulic properties have normally been used in hydrologic models. Soil profile descriptions are the most readily available soils information in the United States. These descriptions contain a wealth of qualitative information which needs to be incorporated into procedures for describing on soil water retention and hydraulic conductivity. Using NRCS's national soil data base we developed procedures for predicting water retention at -33 kPa and -1500 kPa matric potential based on soil survey qualitative profile descriptions. The qualitative information used in the pedotransfer functions were USDA soil texture classes, structure, grade, size and shape classes, dry and moist consistency classes and stickness,plasticity classes, topographic features, organic matter and taxonomic units which are subjectively estimated in the field and are part of every soil profile description. National pedotransfer functions which predict soil hydraulic properties (water retention and hydraulic conductivity) based on various levels of quantitative and qualitative soil survey information are being developed and incorporated into a decision support system. Also techniques are being developed to scale the hydraulic properties for use with remote sensing information.

# NASA GSFC Hydrological Sciences Branch

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Research Topics:

1. Leading the development of NASA's Global Land Data Assimilation System (GLDAS), which makes use of various new satellite- and ground-based observational products for parameterization, forcing, assimilation, and validation of several sophisticated, offline (not coupled to the atmosphere) land surface models, in order to produce optimal output fields of land surface states and fluxes.

2. Estimating and mapping variations in terrestrial water storage (groundwater, soil moisture, surface water, snow, ice, and wet biomass), via remote sensing and ground-based measurement, high performance numerical modeling, and interpretation of satellite-derived gravity field observations (i.e., from the Gravity Recovery and Climate Experiment (GRACE)).

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Dr. Peters-Lidard's expertise lies primarily in hydrology, focusing on hydroclimatology and hydrometeorology. Dr. Peters-Lidard's long-term research objectives are (1.) Measurement of water and energy fluxes and states via field experiments and remote sensing; (2.) Modeling land-atmosphere interactions using coupled hydrological-meteorological models and High Performance Computing and Communications (HPCC) technologies; (3.) Understanding the space-time structure of precipitation, evapotranspiration and soil moisture and their impact on land-atmosphere interactions; and (4.) Application of improved water and energy process representations in numerical weather prediction, air quality modeling, climate modeling and water resources management. Dr. Peters-Lidard will present examples of current and recent research activities in these areas.

**DAVID L. TOLL**

17 Jan. 2003

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## I. Career Goals

To perform scientific research, management and application in hydrology, microclimatology, and environmental science. Specific goals include application and improvement of land surface water and energy process for improved study of land-atmosphere processes and environmental prediction; development of improved remote sensing of land surface biophysical parameters and application of hydrologic research to water resource management.

## II. Research

- <u>Land Data Assimilation Systems</u>
  - + Surface energy and water balance
  - + Remote sensing inputs to improve modeling
  - + Extend to applications

- <u>Applications Science</u>
  - + Water Quality: Remote sensing and non-point source pollution
  - + Water Resources: water allocation, water use, snow

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Randal Koster is a co-investigator in the NASA Seasonal-to-Interannual Prediction Project (NSIPP), a project that aims to demonstrate the usefulness of remotely sensed data in seasonal forecasting systems. The first of his two key responsibilities in NSIPP is the development and maintenance of a new type of land surface model for AGCMs. The NSIPP Catchment Model goes beyond the standard "one-dimensional layered" AGCM land surface model by treating the subgrid variability of soil moisture statistically, with the applied probability density functions tied sensibly to the topography. The subgrid soil moisture distribution allows an explicit treatment of spatially heterogeneous evaporation and runoff generation.

Koster's second responsibility is to quantify the impact of soil moisture initialization on seasonal forecasts of precipitation and temperature. Forecasting experiments have shown this impact to be strong in some regions. The initial conditions applied to date have been obtained by driving the land surface model with forcing derived from observations. In the near future, these derived initial conditions will be strengthened through the assimilation of remotely-sensed soil moisture.

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Ground-Based Active/Passive Microwave Remote Sensing for Soil Moisture Retrieval

At NASA/GSFC what I do is two-fold. I am currently pursuing my PhD in Environmental Engineering at the Johns Hopkins University in the Department of Geography and Environmental Engineering.

I work under the direction of Dr. Paul R. Houser, Head of the Hydrological Sciences Branch (code 974) at NASA/GSFC. I am working on a project entitled "Quantifying Microwave Transmission through Dynamic Vegetation". The leaders of this project are P. R. Houser, P. O'Neill, and E. Kim.

The proposed project is to quantify the effect of vegetation changes on microwave emission from the land surface through the development and validation of a coupled dynamic vegetation microwave emission model.

In the Summer 2002 experiment at the heavily instrumented USDA-ARS $OPE^3$ (Optimizing Production Inputs for Economic and Environmental Enhancement) field site, most of my efforts were centered around the ground validation measurements. Also, I assist with the data retrieval of the L-Band radiometer (L-Rad) built by Dr. Ed Kim of Code 975 and NASA/GSFC's truck mounted radar.

Improving Plant Photosynthesis and Stomatal Conductance Modeling for Enhanced Land Surface Models and Surface Soil Moisture Data Assimilation Using Kalman Filters

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The Collatz et al. parameterization of leaf photosynthesis-stomatal conductance has been widely applied in land surface parameterization schemes for simulating the land surface CO2 fluxes. However, this popular parameterization model has two aspects to be improved. One is the approach used to solve the model equations. The other is the scaling-up approach for implementing the leaf scale model in canopy simulations. We have developed an analytical solution method to improve the computational efficiency and numerical stability of model solution procedure. For the scaling-up approach we implement the leaf scale model for sunlit leaves and shaded leaves of a plant canopy separately. We then apply these improvements of the photosynthesis-stomatal conductance model to the simplified biosphere model (SSiB), enhancing its capability of simulating land surface CO2 fluxes. The enhanced SSiB model is tested with field observation data sets from two Amazonian field experiments (ABRACOS missions and Manaus Eddy Covariance Study). Simulations of the land surface fluxes of latent heat, sensible heat and soil heat by the enhanced SSiB agree very well with observations with correlation coefficients being larger than 0.80. The correlation coefficient for the daily means of CO2 fluxes between the observations and the simulations of the original photosynthesis-stomatal conductance model is only 0.42 for the Manaus data set. The new scaling-up approach increases the correlation coefficient to 0.84. These results are presented in a paper in press of Ecological Modeling.

In another direction, we have implemented the Extended Kalman Filter (EKF) for assimilating soil moisture data into the MOSAIC model of NASA's Land Data Assimilation System (LDAS). Using the TMI soil moisture retrieval data of SGP99, we have done a series of numerical experiments to test the performance of EKF under various error covariance setups. Understanding the performance of EKF will provide guidance for the validation of AMSR_E soil moisture retrievals using data assimilation approaches. The results of these numerical experiments will be presented.

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Seasonal climate forecasting must rely on the correct initialization of the slow components of the Earth system, namely the oceans and the land surface. My research has focused on land data assimilation or the attempt to merge information from land observations and models in an optimal manner.

In the context of the NASA Seasonal-to-Interannual Prediction Project (NSIPP) we have used twin experiments to compare techniques for soil moisture estimation, including variational methods, the Ensemble Kalman filter (EnKF), and the Extended Kalman filter (EKF). While all methods produce satisfactory estimates, the variational method is more accurate than the EnKF which in turn is more accurate than the EKF. Nevertheless, the EnKF is probably the most suitable approach for land assimilation because it does not require an adjoint (which is rarely available for land models) and because it can account for the widest range of model errors.

Currently we assess the importance of horizontal correlations in background errors for soil moisture initialization of the NSIPP forecast system by comparing a three-dimensional EnKF with a simplified one-dimensional version. In the near future, we plan to produce initial conditions for seasonal hindcasts by assimilating soil moisture data from the Scanning Multichannel Microwave Radiometer (SMMR) and for experimental forecasts by assimilating soil moisture retrievals from the Advanced Microwave Scanning Radiometer (AMSR).

Linking Surface Parameters and Microwave Signatures
Edward J. Kim
NASA/USDA meeting
30 Jan, 2003

As the land packages of GCMs improve, questions have emerged regarding the performance of land surface models in "cold lands" areas, or even simply in the area of higher-fidelity "traditional" soil moisture applications. In either case, the basic tool for developing a physically-based—and therefore non-empirical—understanding of the linkage between surface parameters of interest and remotely observable quantities remains the physically-based forward model. "Cold lands" applications require models where heat and moisture transport include freezing and thawing. The recent Cold Land Processes initiative (NASA, Terrestrial Hydrology) and associated field experiments will provide legacy datasets to greatly improve our understanding of these linkages. With some luck regarding spatial scaling, the efforts should yield improved parameterizations for the modeling of cold lands conditions. On the "warm front", future SMEX campaigns are beginning to explore soil moisture retrieval in more challenging areas as well as the retrieval of surface parameters beyond just soil moisture.

Clearly, to make true progress, one needs both models and observations. Constructing or obtaining suitable models is straightforward in that it does not require special facilities. Examples of modeling efforts abound. Retaining an observational capability is another matter. Access to appropriate experimental data and the ability to design and carry out field observations sets fundamental constraints on a large portion of Terrestrial Hydrology research. I will describe an effort at GSFC to develop observational capabilities tailored to spatial scales from plots to satellite pixels and temporal scales from SGP/SMEX "snapshots" to seasons. In particular, these capabilities are well-poised to address various integral scaling issues.

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## Land Data Assimilation Systems

Accurate initialization of land surface moisture and energy stores is critical in weather and climate prediction because of their regulation of surface water and energy fluxes between the surface and atmosphere over a variety of time scales. Since these are integrated states, errors in land surface forcing and parameterization accumulate in land stores, leading to incorrect surface water and energy partitioning. However, many new land surface observations are becoming available that may provide additional information necessary to constrain the initialization of land surface states critical for weather and climate prediction. These constraints can be imposed in two ways. Firstly, by forcing the land surface primarily by observations (such as precipitation and radiation), the often severe atmospheric numerical weather prediction land surface forcing biases can be avoided. Secondly, by employing land surface data assimilation techniques, observations of land surface storages (soil temperature, soil moisture, and snow depth/cover) can be used to constrain unrealistic simulated storages.

Therefore, high-resolution, continental and global Land Data Assimilation Systems that use relevant remotely-sensed and in-situ observations within a land data assimilation framework have been developed. This development will greatly increase our skill in land surface, weather, and climate prediction, as well as provide high-quality, global land surface *assimilated data fields* that are useful for subsequent research and applications. Analysis of the constant confrontation of model predictions with observations at various time and space scales provides an opportunity to improve our understanding and assessment of the space-time structure of land-atmosphere interaction, the relationship between model estimates and observations of land surface conditions, and the role of the land surface in regulating hydrologic and climatic variability. For more information, please visit *http://ldas.gsfc.nasa.gov*.